A Quick Look at the Scale of HINS RFQ Heating

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The RFQ copper structure has outside dimensions of 10 inches by 10 inches and is approximately 120 inches long. Approximately 60% of the volume is void. See Figure 1. This gives a conservative estimate of the volume of copper as 4800 cubic inches or 78600 cubic cm for a total mass of ~700kg or 1545 lbs.

Taking the specific heat of copper as 385 J/(kg*°K), the heat capacity of the mass is 269 kJ/°K. A single RF pulse of one-millisecond duration at 400kW deposits 400 joules. The temperature rise per pulse with no cooling will be 0.0015°K. The specific rate of temperature rise will be 0.0134°K/hr per watt. At 400kW and 1% duty factor (i.e. 4kW), this becomes 53.5°K/hr.

A more conservative 400kW pulse of 100 microseconds at 1 Hz represents 40W average power. The rate of temperature rise without cooling will be 0.54°K per hour.

The RFQ structure rests on three steel posts for support. Given stainless steel thermal conductivity of 16 watt/meter°K, the temperature rise in °K is 0.06*P*L/A, where P is power in watts, A is cross-sectional area of conductor in square meters and L is length of conductor in meters. Estimating a three square inch by six inch long support as a thermal conductor, L/A is 2/inch or 80/meter and the resulting thermal impedance is 4.8°K per watt. For three supports, this becomes 1.6°K per watt.

For millisecond-scale pulse lengths, low repetition rates (≤ 1% duty cycle) and poor cooling, thermal gradients in the copper structure itself will be negligibly small. Assume all power goes into vane tips and heat must conduct through the narrow vanes into the bulk copper. Model the vanes as 120 inches wide, ¼ inch thick and 1 inch long. This gives an L/A value of 0.033/inch or 1.3/meter. The thermal conductivity of copper is 400 watt/meter°K. Therefore, the temperature rise through one vane is 0.00325°K/watt. For 40 watts and four vanes, this becomes 0.03°K.

Using actual RFQ structure parameters, Tom Page created an ANSYS model and ran the thermal simulation. ANSYS gives the expected 0.014°K/(hr*watt) initial temperature rate of rise and yields a steady state temperature rise of 0.83°K per watt (about a factor of two smaller than the estimate above). See Figure 2. For an input power of 40 watts, the ANSYS model shows an equilibrium temperature rise of 32.5°K. Assuming a simple exponential thermal behavior, the corresponding time constant is about 58 hours.

Given these quantities, a safe range for operating the RFQ without cooling water can be established. Taking a maximum 10°K temperature rise as acceptable (ambient temperature varies on that scale), then the RFQ can safely run indefinitely at 40 watts for eight hours per day five days per week. Blowing air through the water channels can increase this level if necessary.

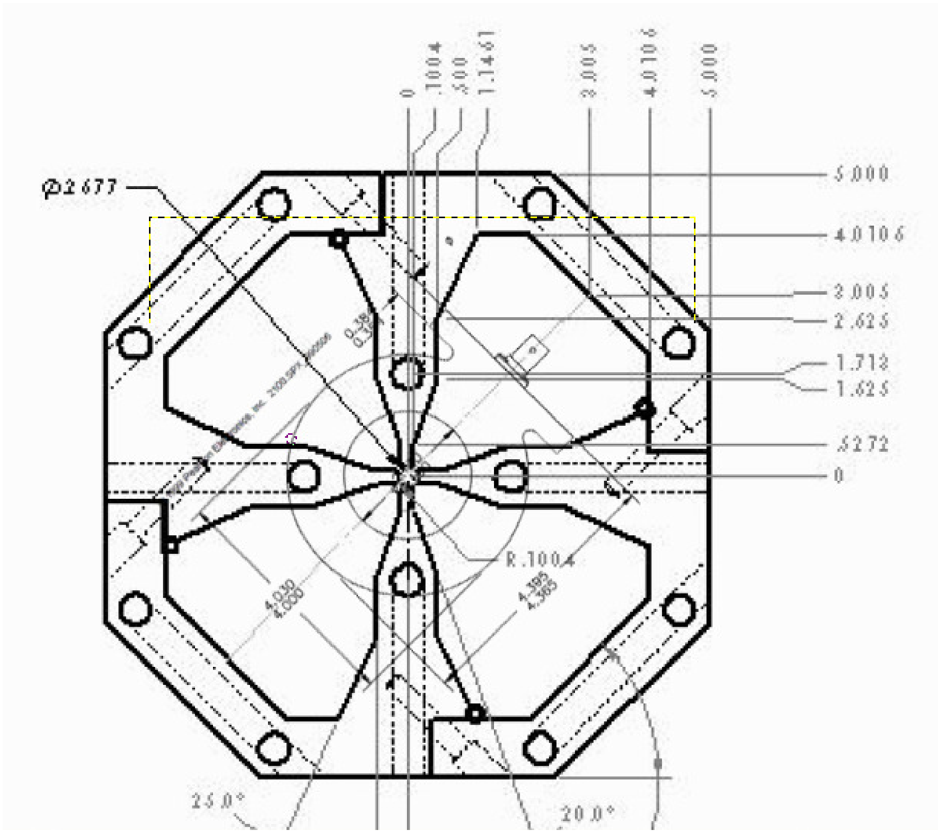

Figure 1. RFQ cross section

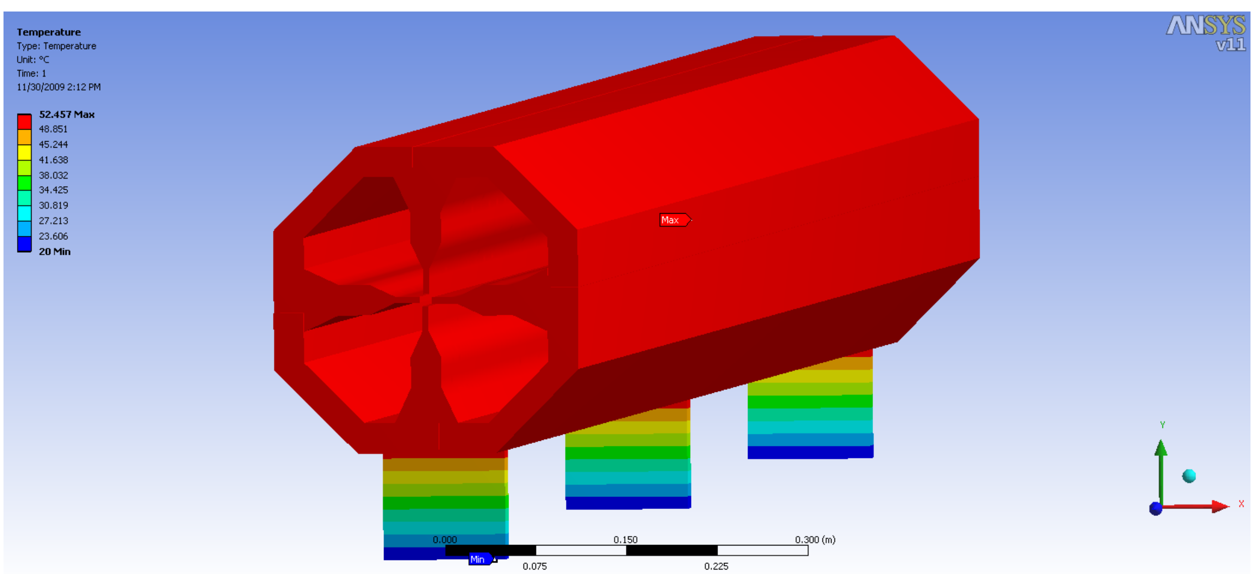

Figure 2. ANSYS thermal model in steady state with 40 watts input heat; 32.4°K temperature rise